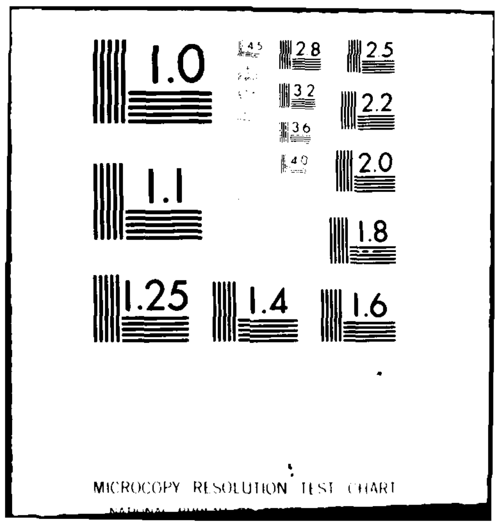
AD-A098 101 QUEENS COLL FLUSHING N Y LABS OF APPLIED PHYSIOLOGY F/G 6/19
INFLUENCE OF INCREMENTAL WORK TASKS ON THERMOREGULATION IN AIR --ETC(U)
DEC 80 J R MAGEL, W D MCARDLE N00014-76-C-0192

UNCLASSIFIED NL

END
DATE
FILMED
5-81
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
MICROCOPY RESOLUTION TEST CHART

LEVEL II

(12)

(9) FINAL TECHNICAL REPORT

OFFICE OF NAVAL RESEARCH

CONTRACT NO. N00014-76-C-0192 (15)

AD A098101

(6)

TITLE: INFLUENCE OF INCREMENTAL WORK TASKS ON THERMOREGULATION IN AIR AND DURING IMMERSION IN 18, 26 AND 33 C WATER: SPECIAL REFERENCE TO MODERATELY FAT SUBJECTS.

(12) 22

(10) John R. Magel, Ph.D.
William D. McArdle, Ph.D.
Laboratory of Applied Physiology
Queens College, Flushing, N. Y. 11367

(11) Dece[redacted]80

401230

81 3 31 003

Abstract

The present investigation has studied thermoregulation in a group of moderately fat (18-22% body fat) college-age men during water immersion, and the interrelationships between temperature (cold stress), work intensity (metabolic stress), and body composition (% body fat). The metabolic, thermal, and cardiovascular adjustments were determined at rest and during graded submaximal exercise in air and during water immersion at 18, 26, and 33 C. Based on the present observations, the following conclusions are warranted: Fat subjects demonstrated slightly higher $\dot{V}O_2$ and HR values in 33 C water than in air. However, in cool (26 C) or cold (18 C) water, fat subjects did not demonstrate any significant change in $\dot{V}O_2$ or HR during rest or submaximum exercise. There were no significant effects of water immersion or temperature on $\dot{V}_E$ in relation to $\dot{V}O_2$ at rest or during submaximum work. Thus, at a particular water temperature, the $\dot{V}_E$ was dependent on $\dot{V}O_2$ during cool and cold water exposure, and did not reflect a basic alteration in the $\dot{V}_E - \dot{V}O_2$ relationship. Rectal temperature (T_r) increased in fat subjects during exercise in 33 C water (+0.4 C) as well as in air (+0.2 C). In cold water (18 C), T_r decreased moderately (-0.2 C) during exercise, but increased slightly in cool (26 C) water (+0.03 C) exercise. Mean skin temperature ($\overline{T}_s$) drifted upward in air (+0.6 C at 33.9 C) and during exercise in 33 C water (+0.6 C at 33.6 C). However, in cool (26 C) and cold (18 C) water, $\overline{T}_s$ declined, and remained fairly close to T_w during submaximal exercise (-0.6 C at 26.5 C in 26 C water; -0.7 C at 19.7 C in 18 C water). In the present data, body fat provided protection to fat subjects exercising in cool (26 C) and cold (18 C) water, but may have produced a mild heat stress in 33 C water. Fat subjects can effectively regulate core temperature in water between 18 C and 26 C due to the insulatory benefits of their body fat. This is especially true when thermoregulatory mechanisms are aided by the increased caloric output of moderate exercise.

Background

Water is an ideal medium for subjecting humans to thermal stress. Temperature can be adjusted rapidly and regulated within relatively narrow limits. Because the thermal conductivity of water is about 25 times that of air, water immersion can provide a considerable thermal stress and bring about metabolic and physiologic thermoregulatory adjustments in relatively short periods of time.

During rest and exercise, similar metabolic and physiologic responses are observed for a naked person in air and water, providing the water temperature is between 30 and 35C (2, 11). However, if water temperature is reduced below 28C, the energy cost of rest and exercise generally increases substantially. This elevated rate of energy metabolism is due mainly to an activation of peripheral cold receptors and a reduction in core temperature, which, in turn, stimulate the shivering response as the body attempts to counteract the loss of heat to the cold water (2, 5, 11, 12). In addition to shivering thermogenesis, specific cariovascular adjustments occur in cold water that more than likely reflect alterations in peripheral blood flow in response to the thermal challenge. We have recently observed that these responses are characterized by a significant bradycardia at rest and in exercise which is accompanied by a proportionate increase in thè stroke volume of the heart (11). As a result, the relationship between cardiac output and oxygen consumption is quite similar regardless of water temperature between 18 and 33C. Because of the great cooling effects of cold water, however, the thermoregulatory mechanisms are often incapable of preventing a fall in core temperature.

Adjustment to cold is not the same for all individuals, and is greatly influenced by a subject's body composition. Pugh and Edholm (13) showed that the rectal temperature of a lean swimmer decreased in 16C water, while a fatter swimmer was able to maintain internal temperature during 30 minutes of swimming.

Keatinge (9) also documented the inverse relationship between mean skinfold thickness and the fall in body temperature at rest during cold water immersion at 15C.

Lean subjects show an exceptionally large increase in metabolism and decrease in heart rate in cold water, whereas the insulatory benefit of body fat provides excellent protection against heat loss for fatter people. In work from our laboratory (11), it was observed that the fatter subjects showed no metabolic or physiologic differences at rest or in exercise in 25C water compared to thermoneutral water (33C). In fact, our fattest subject (20% body fat) sowed no difference in heart rate or metabolism at rest or exercise in 18C water. Similar observations have been reported by Holmér and Bergh (5) who observed a significant shivering thermogenesis and corresponding fall in esophageal temperature in subjects at rest and during swimming in water of 18 and 25C. These researchers also noted the insulatory benefits of body fat as their fatter subjects (classified by skinfold thickness) showed only a small response to the cold water, whereas the esophageal temperature of the lean subjects decreased from 0.2 to 1.6C during submaximal swimming. As the caloric expenditure increased in heavier work, the metabolic and physiologic differences observed in cold and warmer water became smaller suggesting that physical activity may contribute to thermoregulation during cold stress. However, for the leanest subjects, $\dot{V}O_2$ max and work performance were reduced significantly in 18C water.

In warmer water the situation is reversed and body fat becomes a liability, especially during heavy exercise as man tends to store heat. Nadel and coworkers (12) showed that core temperature of competitive swimmers actually increased for their relatively fatter subjects (12.4% body fat estimated from skinfolds) during strenuous exercise in 25 and 33C water.

From the above discussion, it appears that for each individual, a water temperature exists in which the heat generated via shivering and muscular work does not balance the heat flux induced by an elevated convective heat transfer in water. This water temperature could be quite low for fatter subjects, as our data suggest that subjects with approximately 20% body fat can effectively regulate core temperature in water between 18 and 25C (11). This is especially the case when thermoregulation is aided by the increased caloric output of moderate exercise. Based on previous observations by us and others, it also appears that changes in energy metabolism, core temperature, and heart rate can be used to estimate the adequacy of an individual's thermal protection in cold. Since changes in these parameters during rest and exercise at various temperatures are closely related to a person's body composition, measures of body fat may provide significant information for predicting physiologic and performance data in response to thermal stress. We expect relatively fat individuals to show a proportionately smaller metabolic, thermal, and cardiovascular adjustment to cold environments as well as a greater work tolerance in comparison to leaner subjects. Aside from the limited data from Nadel et al. (12), Holmér and Bergh (5), and McArdle and colleagues (11), a precise statement cannot be made as to the influence of body fatness of men and women on thermoregulation at rest and during graded exercise.

Introduction

The present investigation (ONR contract No. N00014-76-0192 for fiscal 1979) has studied thermoregulation of man during water immersion and the interrelationships of temperature (cold stress), work intensity (metabolic stress), and body composition (degree of body fatness). More specifically, the metabolic, thermal, and cardiovascular adjustments were determined at rest and during graded submaximal exercise in air and during water immersion at 18, 26, and 33C.

As part of a 3 Phase Project to study the role of body composition in thermoregulation, the present work evaluated the exercise and thermal responses of a group of college-age men classified as moderately fat (18-22% body fat).

Methods

Subjects: Six college-age male volunteers served as subjects. All subjects were medically cleared, and signed informed consent documents prior to any testing. In addition, the project was approved by the Queens College Committee on the Use of Human Subjects for Research.

Body Composition Evaluation

Prior to the experiment, each subject was evaluated for percent body fat from determinations of body density by underwater weighing. Body density was measured in a large stainless steel tank, with easy entry and exit provided by a built-in step ladder. The underwater weighing technique followed similar procedures described initially in 1942 by Behnke and others (1), with the exception that subjects sat in a specially designed chair during underwater weighing instead of a sling (7, 8). Ten consecutive trials of weighing were made, and an average of the last three trials was used as the true underwater weight score (6, 8). This refinement in technique made it possible to determine body volume with an error no greater than ±1 ml per 1,000 ml of volume measured. Body weight was measured on a Homs beam balance scale to the nearest ±50 grams. Residual lung volume was measured by an oxygen dilution technique with a standard error of measurement of ±26 ml (15). Percent body fat was computed from density by use of an empirical formula developed by Siri (14), where percent fat = 495/density - 450. Subjects were then classified as moderate in body fatness (18-22% body fat).

Temperature Assessment

Deep Body Temperature - Core Temperature (Tc)

Rectal (T_r) was recorded continuously during rest and graded submaximal

exercise in air and in all water conditions. T_r was obtained by means of a rectal temperature probe (Yellow Springs Instruments (Y.S.I. Probe No. 401) inserted approximately 10 cm into the rectum.

Skin Temperature (T_s)

Temperature from 4 skin surface loci were obtained by means of a specially designed, water-proofed thermocouple (Y.S.I. No. 43) affixed to the skin with non-insulatory surgical tape. Mean skin temperature ($\overline{T}_s$) was calculated by appropriate weighting of the individual skin temperatures as follows:

$$\overline{T}_s = 0.16\ T_1 + 0.16\ T_2 + 0.36\ T_3 + 0.32\ T_4 \quad (12)$$

where:

T_1 = upper arm temperature (over the middle deltoid muscle); T_2 = forearm temperature (over the brachio-radialis muscle); T_3 = chest temperature (over the pectoralis major approximately 2 cm above the nipple); and T_4 = thigh temperature (over the upper portion of the rectus femoris midway between the knee and hip joints). All skin temperatures were recorded from the right side of the body.

Water temperature was measured from a thermocouple in the water placed approximately 5 cm from the subject's chest.

Both T_c and T_s were monitored continuously by direct feed into a calibrated, battery operated multi-channel tele-thermomenter (Yellow Springs Instruments model No. 43).

Exercise Experiments

A. Water Tank.

The water tank for rest and exercise experiments was 122 cm wide, 122 cm long, and 183 cm deep. Water was circulated and filtered to assure adequate mixing, and temperature was maintained within ±0.5°C.

B. Protocol.

During the water experiments, subjects were immersed to the level of

of the first thoracic vertebrae. All subjects were familiarized with the testing apparatus and test procedures prior to collection of experimental data. Metabolic measurements, heart rate and rectal and skin temperatures were measured in air and in each of the three different water temperatures. The subjects were tested in a systematically rotated design to minimize a possible ordering effect due to test sequence. One-third (n=2) of the subjects were tested first either in air or in water at 18, 26, or 33 C, and at least two days inactivity preceded each test. Subjects were familiarized with the testing apparatus and test procedures on separate days prior to data collection.

C. Exercise Apparatus.

Work was performed on a specially designed air-water cycle ergometer described by Craig and others (3, 4), and used by us previously (11). Both arm and leg pedals were utilized and placed so that forces were exerted as much as possible in the horizontal plane. This method of exercise minimized the effects of gravity being used as an aid to working the pedals, and makes it possible to compare work in air and in water (2, 3, 11). The sprockets for the arm and leg pedals were connected by a chain with the lower sprocket also connected to a lead weighted flywheel. The flywheel was connected by a V-belt to an electrical alternator. The field of the alternator was supplied by a constant 12 v current from a battery. Output voltage was kept constant by a voltage regulator and amperage was determined by a variable output resistance.

D. Exercise Protocol.

The subject sat quietly on the ergometer for 10-min prior to work. Subjects were exercised by use of a continuous graded test in air (25-27°C) and in water of 18, 26 and 33 C. Subjects pedalled at 30 rpm and worked for 10-min each at 0, 24, 48, and 72 watts. At least two days of inactivity

preceded the administration of a test under each environmental condition. In order to evaluate the contribution of exercise to thermoregulation, all subjects were also measured in air and immersed in each of the 3 water conditions at rest for periods of time equal in length to the exercise testing periods. This was done in order to match the duration of exercise exposure in the 4 environmental conditions.

In exercise tests, expired air was collected following the 10-min rest period and during the final minute of each work level. Heart rate and respiratory frequency were continuously monitored by means of radio-telemetry. All temperatures (rectal and skin) were recorded every two minutes during rest and exercise at each work level. Subjects were removed from the tank in water experiments when internal body temperature (T_c) dropped more than 2°C from values taken in air prior to immersion.

Respiratory Gas Analysis

Oxygen consumption ($\dot{V}O_2$) and carbon dioxide output ($\dot{V}CO_2$) were measured by open-circuit spirometry utilizing meteorological ballons for collection of expired air. Minute pulmonary volumes ($\dot{V}_E$) were measured with a Parkinson-Cowan CD_4 dry gas meter (Instrumentation Associates Inc., New York). Expired gas samples were analyzed immediately for oxygen content by passing the gas through an Applied Electrochemistry S-3A oxygen analyzer, and for CO_2 content by passing the gas through a rapid infrared CO_2 analyzer (Godart Capnograph; Instrumetation Associates Inc., New York). Outputs from the CO_2 gas analyzer were recorded on a Physiograph 4-A rectilinear recorder (Narco Bio-Systems, Inc., Texas). Prior to each test, the gas analyzers were calibrated with test gases previously verified with the Haldane-Henderson apparatus.

RESULTS AND DISCUSSION

Physical Characteristics

Values for age, height, weight, and residual lung volume (RV) for moderately fat subjects are presented in Table 1. Fat subjects averaged 20.1% body fat. Accompanying values for body density, fat weight, and lean body weight (LBW) substantiated the significant differences in body composition between fat, lean and normal subjects reported previously (ONR Progress Report for fiscal 1978). Values for RV were within normal range for male subjects of this age and height.

Metabolic and Physiologic Response

Most metabolic and physiologic adjustments to work in air and water of 33 C were essentially similar for fat subjects (Tables 2 and 3). However, in 33 C water, $\dot{V}O_2$ and heart rate were slightly higher in relation to external work load for fat subjects. Essentially, these observations are in agreement with our previous contracted work (ONR contract No. N00014-72A-0406-0005) (10) which indicated that the physiologic and metabolic responses are no different in air and water when water temperature ranges between 30-35 C. Presently, this also appears to be true for subjects classified as moderately fat in terms of body fatness.

Tables 4 and 5 show the thermal and physiologic adjustments of moderately fat subjects in 26 C and 18 C water. $\dot{V}O_2$ was higher, but not significantly so, in 18 C water when compared to air and 33 C water. The increase in $\dot{V}O_2$ during submaximal work in colder water (18 C) was not of the same magnitude as that observed in lean and normal subjects when compared to air or warm water values. The lack of significant shivering or increase in $\dot{V}O_2$ for fat subjects in cold water was due, more than likely, to the thermoinsulatory benefits of body fat in these subjects which was sufficient to avoid a cold stress.

The heart rate (HR) response (while linear with external work and $\dot{V}O_2$ as

in air and in warm water at 33 C), was only slightly depressed in 18 C water as compared to 33 C water at equivalent levels of oxygen consumption. In subjects of normal body fatness at a given submaximal $\dot{V}O_2$, HR averaged about 6 beats $\cdot$ min^{-1} lower in 26 C water, and 17 beats $\cdot$ min^{-1} lower in 18 C water than equivalent values in 33 C water or in air. For moderately fat subjects, however, heart rate was similar in 26 C and 33 C water, and averaged only 3-5 beats $\cdot$ min^{-1} lower in 18 C water. HR at similar $\dot{V}O_2$ in various water temperatures were determined by means of regression analysis established from each subject's HR-$\dot{V}O_2$ line. Values for lean subjects in similar comparisons were 10 beats $\cdot$ min^{-1} and 20 beats $\cdot$ min^{-1} lower, respectively. However, the exercise bradycardia in water was not a water effect per se, but a direct response to temperature. In lean subjects, a decrease in water temperature caused a significant shift to the right in the HR-$\dot{V}O_2$ line with the lowest exercise HR being observed in 18 C water. While the cold water bradycardia was also observed in normal subjects, the magnitude of the response was significantly less, and was essentially nonexistent in fat subjects.

As observed in lean and normal subjects, immersion in 18 C water produced significant increases in $\dot{V}O_2$ during work, a reduction in HR, and an accompanying shift to the right in the HR-$\dot{V}O_2$ line. For both groups, the magnitude of these changes was greater in 18 C than 26 C water. On the other hand, fat subjects in the present study did not exhibit any shift in the HR-$\dot{V}O_2$ line, and, in fact, exhibited a mild heat stress in 33 C water with body temperatures being somewhat higher than in air.

Pulmonary ventilation ($\dot{V}_E$)

There were no significant effects of water immersion or temperature on $\dot{V}_E$ in relation to $\dot{V}O_2$ at rest or during work. Thus, at a particular water temperature, the $\dot{V}_E$ for fat subjects was dependent on their $\dot{V}O_2$ during cold water exposure, and did not reflect a basic alteration in the $\dot{V}_E$-$\dot{V}O_2$ relationship. As

a response to increasing metabolic demands, $\dot{V}_E$ increased progressively and essentially linearly during submaximum work in air and in all water temperatures. At equal levels of $\dot{V}O_2$, similar values for $\dot{V}_E$ indicated the linear nature of the ventilatory response.

Body Temperature - Rectal (T_r)

During work in air and 33° C water, T_r tended to drift upward as work progressed (Tables 2 and 3). In relatively cool water (26 C) (Table 4), T_r increased slightly with increasing work in fat subjects (T_r increased approximately 0.3°C over the entire range of work), and there was no evidence of cold discomfort or shivering throughout the exercise task. In cold water (18 C) (Table 5), the effects of immersion (cold exposure) during work were somewhat more noticeable, even though T_r decreased only 0.2°C over the entire immersion period. As observed previously (ONR Progress Report for fiscal 1978), the greatest thermal stress in cold water was experienced by lean subjects. T_r dropped about 2.0°C at the end of the work task compared to 1.3°C in normal subjects. In contrast T_r dropped only 0.2°C in fat subjects. Lean and normal subjects had complained of cold discomfort in cold water, and were uncontrollably shivering at rest and during submaximum work. Fat subjects, however, appeared relatively comfortable in both cool (26 C) and cold (18 C) water.

Skin Temperature - ($\bar{T}_s$)

Mean skin temperature ($\bar{T}_s$) was highly related to water temperature and showed slight differences in relation to body composition. For lean subjects, during rest and exercise in 18 C water, $\bar{T}_s$ averaged about 2.2 C above water temperature (T_w) throughout the work range. Fat subjects tended to show lower skin temperatures (19.6°C). In 26 C water $\bar{T}_s$ averaged about 0.8 C higher than T_w in all groups. In 33 C water $\bar{T}_s$ was only 0.3 C higher than T_w for lean and normal subjects. However, fat subjects showed $\bar{T}_s$ averaging 0.7°C higher than

T_w in 33 C water. During exercise in air $\bar{T}_s$ increased about 1 C (0.7 - 1.4 C) from the beginning of work to the completion of the test for all subjects.

Even though T_c did not remain stable in cool (26 C) or cold water (18 C) for both lean and normal subjects, it did for moderately fat subjects. In lean and normal subjects, the exercise task contributed to thermoregulation by preventing further, perhaps drastic, reductions in T_c. This was demonstrated by having subjects attempt to sit at rest for identical time durations at which they exercised in each water temperature. They were unable to do so, and subjects either removed themselves from the water, or T_c dropped to a point where it was prudent to terminate the test. None of the lean subjects could tolerate immersion at rest in 18 C water for longer than 15 min, while the normal group averaged 24 min. In 26 C water lean subjects tolerated immersion for up to 26 min before T_c dropped 2 C accompanied by violent shivering when they asked to be removed. Subjects of normal body fatness remained immersed on the average for 35 min. Both lean and normal subjects tolerated 33 C water quite comfortably for the full 40 min rest period. On the other hand, fat subjects sat quite comfortably in all water temperatures for time durations that were similar to exercise conditions without evidence of thermal (cold) stress.

Summary

Based on the present and previous observations from ONR contract No. N00014-76-C-0192, the following conclusions are warranted:

1. Moderately fat subjects (18-22% body fat) demonstrated slightly higher $\dot{V}O_2$ and HR values in 33 C water than in air during rest and graded submaximum exercise. Lean (<10% body fat) and normal (13-16% body fat) subjects showed similar $\dot{V}O_2$ and HR values during rest and exercise in 33 C water as compared to air. However, while fat subjects did not demonstrate any significant change in $\dot{V}O_2$ or HR during rest or submaximum exercise in 26 C or 18 C water, lean

subjects showed significantly higher $\dot{V}O_2$ and significantly lower HR during rest and exercise in 26 C and 18 C water in comparison to air or 33 C water. The increase in $\dot{V}O_2$ was more pronounced in cold (18 C) water. Normal subjects showed similar changes in $\dot{V}O_2$ and HR in 18 C water, but to a lesser degree than lean subjects. In 26 C water, normal subjects demonstrated a significant increase in $\dot{V}O_2$ at rest only, but again not to the same degree as lean subjects.

2. There were no significant effects of water immersion or temperature on $\dot{V}_E$ in relation to $\dot{V}O_2$ at rest or during submaximum work in either lean, normal or moderately fat subjects. Thus, at a particular water temperature, the $\dot{V}_E$ was dependent on $\dot{V}O_2$ during cool (26 C) and cold (18 C) water exposure, and did not reflect a basic alteration in the $\dot{V}_E$ - $\dot{V}O_2$ relationship. As a response to increasing metabolic demands, $\dot{V}_E$ increased progressively and essentially linearly during submaximum work in air and in all water temperatures.

3. Rectal temperature increased in fat subjects during exercise in 33 C water (+0.4 C) as well as in air (+0.2 C). In cold water (18 C), T_r decreased moderately (-0.2 C) during exercise, but increased slightly in cool (26 C) water (+0.03 C) exercise. In contrast, lean and normal subjects showed decreases in T_r during exercise in all water temperatures, with the greatest reductions in core temperature occurring in cold water (lean subjects: -0.3 C in 33 C water; -0.8 C in 26 C water; and -1.2 C in 18 C water; normal subjects: -0.2 C in 33 C water; -0.5 C water; and -0.7 C in 18 C water). However, during exercis in air lean (+0.2 C) and normal (+0.3 C) subjects showed similar increases in T_r as fat subjects (+0.2 C).

4. Mean skin temperature ($\overline{T}_s$) drifted upward for all subjects during exercise in air (lean: +0.4 C at 33.7 C; normal +0.7 C at 33.5 C; and fat: +0.6 C at 33.9 C), and for fat subjects during exercise in 33 C water (+0.6 C at 33.6 C).

$\bar{T}_s$ was somewhat lower in lean (33.1 C) and normal (33.4 C) subjects during exercise in 33 C water. However, during submaximum exercise in 26 C and 18 C water, $\bar{T}_s$ declined, and remained closer to water temperature (T_w) in fat subjects (-0.6 C at 26.5 C in 26 C water; -0.7 C at 19.7 C in 18 C water) than in lean (-0.6 C at 26.9 C in 26 C water; -0.3 at 20.2 C in 18 C water) or normal (-0.5 C at 26.6 C in 26 C water; -0.4 at 20.1 C in 18 C water) subjects.

Conclusion

The present findings support the concept that heat flows down the thermal gradients $T_{core} - \bar{T}_s$ (heat produced and stored in the body core flows to skin) and $\bar{T}_s - T_w$ (loss of heat from skin to water). The rate of heat flow is affected by the nature of two parallel resistors, one fixed, the other variable. The fixed resistor, which is the layer of body fat, offers resistance to heat flow due to its insulatory characteristics. The other resistor, peripheral circulation, varies in its heat transfer characteristics in direct relation to the degree of vasoconstriction/vasodilation of the body vessels and the total volume of blood available for heat exchange. In the present data, body fat provided protection to subjects exercising in cool (26 C) and cold (18 C) water, but may have produced a mild heat stress in 33 C water for fat subjects. Clearly, a major source for individual differences in the rate of heat loss for subjects during cold water immersion was insulation provided by body fat. However, for subjects who are lean or normal in body fatness, even exercise of between 12-15 kcal min^{-1} was insufficient to counteract the heat loss of the body to the water, and, as a result, T_{core} decreased. However, fat subjects (18-22% body fat) can effectively regulate core temperature in water between 18 C and 26 C due to the insulatory benefits of their body fat. This is especially true when thermoregulatory mechanisms are aided by the increased caloric output of moderate exercise.

REFERENCES

1. Behnke, A. R. and Welham, W. C. The specific gravity of healthy men. J. Amer. Med. Assoc. 118:495-496, 1942.
2. Craig, A. B., Jr. and M. Dvorak. Thermal regulation of man exercising during water immersion. J. Appl. Physiol. 25:28-35, 1968.
3. Craig, A. B., Jr. and M. Dvorak. Comparison of exercise in air and in water of different temperatures. Med. Sci. in Sports. 1:124-130, 1969.
4. Craig, A. B., Jr. and W. L. Medd. Man's response to breath-hold exercise in air and in water. J. Appl. Physiol. 24:773-777, 1968.
5. Holmér, I. and V. Bergh. Metabolic and thermal responses to swimming in water at varying temperatures. J. Appl. Physiol. 37:702-705, 1974.
6. Katch, F. I. Practice curves and errors of measurement in estimating underwater weight by hydrostatic weighing. Med. Sci. Sports 1:212-216, 1969.
7. Katch, F. I. and W. D. McArdle. Prediction of body density from simple anthropometric measurements in college-age men and women. Human Biology 45:445-454, 1973.
8. Katch, F. I., E. D. Michael and S. M. Horvath. Estimation of body volume by underwater weighing; description of a sample method. J. Appl. Physiol. 23:811-813, 1967.
9. Keatinge, W. R. The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow, and metabolic rate of men in cold water. J. Physiol., London 153:166-178, 1960.
10. Magel, J. R., W. D. McArdle, M. Toner and D. J. Delio. Metabolic and cardiovascular adjustment to arm training. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 45:75-79, 1978.
11. McArdle, W. D., J. R. Magel, G. S. Lesmes and G. S. Pechar. Metabolic and cardiovascular adjustment to work in air and water at 18, 26 and 33°C. J. Appl. Physiol. 40:85-90, 1976.

12. Nadel, E. R., I. Holmér, V. Bergh, P.-O Åstrand and J. A. J. Stolwijk. Energy exchange of swimming man. J. Appl. Physiol. 36:465-471, 1974.

13. Pugh, L. C. G. and O. G. E. Edholm. The physiology of channel swimmers. Lancet. 2:761-768, 1955.

14. Siri, W. E. Gross Composition of the Body. Advances in Biological and Medical Physics. 4:239-272, 1956.

15. Wilmore, J. H. A simplified method for determination of residual lung volumes. J. Appl. Physiol. 27:96-100, 1969.

TABLE 1. Physical characteristics of moderately fat subjects (18-22% body fat)

Subject	Age, yr	Wt, kg	Ht, cm	RV, ml BTPS	Body Density $gm \cdot ml^{-1}$	Body Fat %	Body Fat kg	LBW, kg
RF	22	82.2	178	1323	1.0489	21.9	18.0	64.2
DC	19	76.5	175	1178	1.0549	19.2	14.7	61.8
JM	21	81.1	180	1461	1.0523	20.4	16.5	64.6
WM	20	74.5	173	1262	1.0503	21.3	15.9	58.6
JF	20	73.4	174	1292	1.0575	18.1	13.3	60.1
RH	23	78.6	177	1356	1.0534	19.9	15.6	63.0
$\bar{X}$	20.8	77.7	176.2	1312	1.0529	20.13	15.67	62.05
±SD	±1.3	±3.2	±2.4	±87	±.0028	±1.27	±1.46	±2.15

RV = residual lung volume in ml, BTPS; LBW = lean body weight in kg.

TABLE 2. Metabolic, cardiovascular and thermal adjustments of moderately fat subjects at rest and during submaximal work in air (n=6)

Variable	Rest	0 watts	24 watts	48 watts	72 watts
$\dot{V}O_2$, $ml \cdot min^{-1}$	298 ±46	750 ±74	1151 ±116	1606 ±167	2111 ±216
HR, $beats \cdot min^{-1}$*	64.0 ±5.2	80.8 ±9.1	93.3 ±10.1	109.5 ±11.1	127.8 ±13.3
$\dot{V}_E$, $l \cdot min^{-1}$ BTPS*	9.2 ±2.8	18.4 ±4.3	29.3 ±6.8	36.4 ±7.8	49.6 ±9.9
Body Temp °C					
Rectal	37.3 ±.20	37.3 ±.21	37.4 ±.24	34.2 ±.25	37.8 ±.30
Mean Skin	33.4 ±.30	33.6 ±.39	33.8 ±.40	37.5 ±.41	34.4 ±.48

*Values for HR and $\dot{V}_E$ determined at $\dot{V}O_2$ in table from regression analysis.

TABLE 3. Metabolic, cardiovascular and thermal adjustments of moderately fat subjects at rest and during submaximal work in 33 C water (n=6)

Variable	Rest	0 watts	24 watts	48 watts	72 watts
$\dot{V}O_2$, $ml \cdot min^{-1}$	303 ±41	759 ±66	1171 ±110	1628 ±171	2137 ±204
HR, $beats \cdot min^{-1}$*	68.3 ±5.6	82.8 ±8.8	95.3 ±9.8	112.3 ±10.4	129.7 ±12.6
$\dot{V}_E$, $l \cdot min^{-1}$ BTPS*	10.1 ±3.5	19.9 ±4.8	30.2 ±7.2	37.3 ±6.9	50.2 ±9.1
Body Temp °C					
Rectal	37.4 ±.22	37.4 ±.21	37.6 ±.24	37.8 ±.25	38.2 ±.31
Mean Skin	33.4 ±.28	33.2 ±.41	33.4 ±.44	33.8 ±.49	34.2 ±.50

*Values for HR and $\dot{V}_E$ determined at $\dot{V}O_2$ in table from regression analysis.

TABLE 4. Metabolic, cardiovascular and thermal adjustments of moderately fat subjects at rest and during submaximal work in 26 C water (n-6).

Variable	Rest	0 watts	24 watts	48 watts	72 watts
$\dot{V}O_2$, ml·min^{-1}	313 ±36	768 ±71	1180 ±114	1641 ±178	2145 ±199
HR, beats·min^{-1}	69.6 ±6.0	83.3 ±9.0	95.2 ±9.2	110.1 ±11.3	126.8 ±12.3
$\dot{V}_E$, l·min^{-1} BTPS*	9.7 ±3.2	21.2 ±5.1	33.3 ±6.8	38.1 ±8.1	51.7 ±10.2
Body Temp °C					
Rectal	37.3 ±.27	37.2 ±.31	37.2 ±.26	37.4 ±.28	37.5 ±.33
Mean Skin	26.9 ±.31	26.8 ±.37	26.4 ±.41	26.2 ±.44	26.0 ±.52

*Values for HR and $\dot{V}_E$ determined at $\dot{V}O_2$ in table from regression analysis.

TABLE 5. Metabolic, cardiovascular and thermal adjustments of moderately fat subjects at rest and during submaximal work in 18 C water (n=6)

Variable	Rest	0 watts	24 watts	48 watts	72 watts
$\dot{V}O_2$, $ml \cdot min^{-1}$	368 ±41	788 ±68	1214 ±121	1668 ±172	2175 ±201
HR, $beats \cdot min^{-1}$*	66.2 ±6.6	80.4 ±8.1	92.4 ±9.0	106.1 ±10.2	122.3 ±11.7
$\dot{V}_E$ $l \cdot min^{-1}$ BTPS*	10.1 ±2.8	22.0 ±6.3	35.2 ±7.1	39.9 ±8.7	53.5 ±9.9
Body Temp °C					
Rectal	37.4 ±.22	37.2 ±.30	37.2 ±.27	37.2 ±.29	37.2 ±.33
Mean Skin	20.2 ±.33	20.0 ±.37	19.7 ±.41	19.4 ±.48	19.0 ±.51

*Values for HR and $\dot{V}_E$ determined at $\dot{V}O_2$ in table from regression analysis.


-8